THE PARALLAX OF THE ORION NEBULA

By William H. Pickering

In *Harvard Circular*, **205**, the writer obtained the value $0''.0005$ for the parallax of this object. In *Contributions of the Mount Wilson Solar Observatory*, **147**, 62, just published, Professor Kapteyn obtains the value $0''.0054 \pm 0''.0009$. Since both results were deduced by practically the same method, that of comparing the brightness of the stars associated with the nebula, with the brightness of stars of the same types, whose distance was assumed to be known, it is a matter of interest to determine why such divergent results should have been obtained. The explanation is twofold—different data and different constants.

Professor Kapteyn used only the brightest stars in the nebula, those whose type was known with the greatest certainty, and extending down to magnitude 9.5. He selected from these the magnitude which appeared to him to represent the greatest number of stars, and based his result on this magnitude. Two determinations were made, one using the stars of spectral classes B0 to B5, and the other stars of spectral classes B8 to B9.

The writer based his results on an investigation, *H. A.*, **32**, 36, in which he had measured the photographic magnitudes of something over 800 stars in the nebula and its immediate vicinity, and compared them with earlier visual magnitudes measured by G. P. Bond. Certain necessary corrections were applied to Bond's measures, and the stars were then divided into two groups, those that were brighter photographically than visually, and those that were fainter. The former were called blue stars, and the latter white. In *Circular*, **205**, he showed that there was a well-defined cluster associated with the nebula, but that this cluster contained few white stars below magnitude 15, and few blue ones below magnitude 14. In short, the cluster came to an end at this point. We had reached and passed the limiting magnitude, and no more stars were likely to be discovered in it by an increase of telescopic power. Any stars added would be merely superposed upon it from outside regions.

While the types of these fainter stars were not known with the same accuracy as those of the brighter ones, on which they were based, the investigation had the advantage that the data were complete, and a slight error in the assumed type should make no

great difference in the resulting parallax. Instead of selecting by examination what seemed to be the most prevalent type, the writer took the mean magnitude of all the blue stars, some seventy in number, that were clearly associated with the nebula. Herein lay the chief difference in the methods of the two investigators. As a result, the writer obtained an appreciably fainter magnitude than Professor Kapteyn, which is one reason why the latter's value for the parallax is larger.

With regard to the constants employed, the earlier investigation labored under a certain disadvantage, because while the writer employed the best values obtainable at the time, yet since it was published, new values differing very materially from the older ones have been found, which are probably more accurate. This difference is so serious that the writer has decided to re-determine his value of the parallax, employing exclusively the new values of the constants. The type of spectrum which he selected for his blue stars was B2. This type, according to the data and formula given by Russell, *Popular Astronomy*, 1914, **22**, 331, corresponds to an absolute magnitude of -1.0. According to Kapteyn's just published work, above mentioned, page 84, this type would correspond more nearly to an absolute magnitude of $+1.0$. A diminution of two magnitudes would of itself increase the resulting parallax 2.5 times.

Of sixty stars in the constellation of *Orion* belonging to types O and B, ninety per cent were of type B3, and bluer. For this reason we selected type B2 for the blue stars. According to a table published by Kapteyn, page 58, based on recently determined but unpublished Harvard results, it appears that the fainter stars of type B are redder than the brighter ones, which is indeed not unnatural. The blue star of average brightness in the nebula is of magnitude 10.5. An inspection of the table leads to the conclusion that the average blue star of this brightness is probably of type B7, but can hardly be bluer than type A. The absolute magnitude of the average star of type B7, by interpolation, according to Kapteyn, is $+2.0$. This is three magnitudes or sixteen times fainter than the value obtained from our earlier constants, and increases the earlier value of the parallax four times, to $0''.0020$. The corresponding distance would be 50 dekaparsecs, or 1600 light years. The actual reduction is made by means of the formula $m-M=5 \log d$, where m and M are the apparent and absolute

magnitudes 10.5 and 2.0, respectively, and d the distance in dekaparsecs. It is useless to attempt to furnish a value based on the white stars or a resulting probable error in a case like this, where the values adopted depend so largely on estimates. The best we can do, perhaps, is to judge that the error is not likely to exceed $0''.0010$. A probable error attached to what is in any case ultimately an estimate, a matter of judgment, leaves on the mind of the reader an impression of accuracy which is often in no wise justified by the facts.

A striking feature of this region of the heavens is the great range in the absolute magnitude of the stars of type B. The photometric difference in magnitude between β *Orionis* and its companion, distance $9''.1$, according to *H. A.*, **64**, 167, is 6.32. β is therefore 337 times as bright. The photographic brightness of the fifth and sixth stars in the trapezium of the great nebula was found to be 9.4 and 9.0. Unless they are redder than their brighter components their visual magnitudes must be 9.8 and 9.4. Burnham describes them both as 11.0, which would make them very blue indeed. Even if they are no fainter than 10, the range between them and ι *Orionis*, which is clearly connected with the nebula, as shown in *Circular*, **205**, is seven magnitudes, or 625 times. Extending the range down to the faintest blue stars connected with the nebula, which we may assume to be of magnitude 13.5, gives us a difference of 10.5 magnitudes, or 16,000 times, and if we include β *Orionis*, magnitude $+0.3$, which Kapteyn places but slightly nearer to the Sun, and which therefore becomes six times brighter than ι, we have a total range of 100,000. There are few types of stars which show so great a range of brightness as type B. It is therefore important that as many stars as possible should be included in any investigation of the distance of this type.

With a parallax of $0''.0020$ the value of $m-M$ is, as we have seen, 8.5 magnitudes. Similarly with Kapteyn's parallax of $0''.0054$ the difference is 6.3. The apparent magnitude of ι *Orionis* is 2.9. Its absolute magnitude assuming a parallax of $0''.0020$ is consequently -5.6. Since the absolute magnitude of the Sun is $+4.8$, we find that the luminosity of ι is 14,500, and of β 87,000, the Sun's luminosity being taken as the unit. According to Kapteyn these values would be 1,900 and 11,400.

While all of these figures are strikingly large, we can judge of the plausibility of a parallax more satisfactorily by means of the

minimum values, since the maximum possible brightness of a star, especially in the case of an object such as the *Orion* nebula is necessarily very uncertain. If we consider the faintest blue stars in the nebula to be of magnitude 13.5, then their absolute magnitude with parallax 0".0020 will be +5.0, or about the same as that of our Sun. According to Russell, *Pop. Astr.*, 1914, **22**, 339, the surface brightness of a star of type B7 would be nine times that of our solar unit, and its density about one-tenth as great. Therefore their diameters must be one-third that of the Sun, and their masses one three-hundredth, or about four times that of *Jupiter*. With Kapteyn's parallax the masses would be reduced twenty times more. These figures are strikingly small.

It may be that Russell's values of the absolute magnitude of the stars of types A and B are not quite so far out of the way as Kapteyn's results would seem to imply, and that by increasing the parallax from 0".0005 to 0".0020 we may have brought the nebula rather too near us, but it certainly seems unlikely that it should be nearer still, and that these stars should be still smaller.

There seems to be only one way of avoiding the difficulty of supposing all the bright stars of *Orion* to be supergiants, and that is to assume that all the fainter blue stars are really somewhat reddish. If we assume those of magnitude 10.5 to be dwarfs, of type A7, and absolute magnitudes 5.2, this will permit us to adopt as large a parallax as 0".0054. In that case we must remember that there is a considerable body of blue stars outside of the region that we have considered, but obviously connected with the nebula, besides the thirty-five blue stars within it, that are fainter than magnitude 10.5. Some of these are as faint at least as magnitude 13.5, and must be redder than type A7. Besides these there is a great mass of white stars, some still fainter, yet which are clearly associated with the nebula. These must be redder still—probably of types G and K. We are not in the habit of associating dwarfs of these types with nebulae, and particularly with one capable at the same time of producing such stars as those of types Oe5 and B0. Yet this seems to be the only alternative if we wish to adopt a large parallax such as Kapteyn's for the nebula, and refuse to believe it possible for a star to be 100,000 times as bright as our Sun. It is clear that this question can only be satisfactorily settled when a reliable determination of the types of these fainter stars has been made.

In this connection it may be mentioned that Shapley has pointed out, accepting Kapteyn's value of the parallax, that of the "one hundred stars within two or three degrees of the trapezium that are supposed to be definitely variable, nearly all are fainter than the fourteenth magnitude at maximum," so that "the average absolute brightness at maximum is only about a tenth that of the Sun, and at minimum less than a twentieth. Apparently they are dwarfs, while all other variable stars—Cepheids, eclipsing binaries, long-period variables (at maximum)—are typically objects of high luminosity." *Contributions from the Mount Wilson Solar Observatory*, **156**, 12. Indeed it would seem from one point of view, that the *Orion* nebula must be the place of very small things.

With a parallax of 0".0054 the absolute magnitude of these variables at maximum is only 7.7. With a parallax of 0".0020 their absolute magnitude is 5.5, still a little fainter than the Sun. If the writer has erred in the constants that he has adopted in this second determination of the parallax, he believes it is on the side of bringing the nebula too near us, rather than of making it too remote. The luminosity of the stars, if altered, should be made greater, rather than less, and the true value of the parallax made to lie between 0".0005 and 0".0020, depending on the value of the constants that we decide to adopt. We will, however, temporarily accept Kapteyn's constants, and call the value of the parallax **0".0020**, but we must consider this figure to be a maximum value. In closing this paper it may be pointed out that the parallax first assigned to this object by the writer, some twenty-five years ago, based on the proper motions of nineteen stars associated with it, *H. A.*, **32**, 80, of 0".003, lies between his last value and that of Kapteyn.

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